ON THE

PROXIMATE CAUSE OF DEATH

AFTER THE

SPONTANEOUS INTRODUCTION OF AIR INTO THE VEINS.

WITH

SOME REMARKS ON THE TREATMENT OF THAT ACCIDENT.

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The subject of the Introduction of Air into the Veins has received, within the last few years, a considerable share of the attention of physiologists as well as of practical surgeons;—amongst whom I may mention Amussat, Velpeau, Bouillaud, Poiseuille, and Cormack. Much of the knowledge that we possess on this question is also due to the labours of the Commission appointed for its investigation by the Academy of Medicine of Paris, a report of the proceedings of which will be found in the sixth volume of the British and Foreign Medical Review.

The result of the several inquiries that have thus been instituted has been, that the possibility of the spontaneous introduction of air into the veins during surgical operations, or, in consequence of accidental wounds, has been incontestibly determined; the phenomena that accompany the accident, and the circumstances that may occasion it ascertained; and the situations in which only it can happen, accurately pointed out. As these points, then, may be looked upon as definitely settled, I shall not again refer to them,

but shall confine the observations that I have the honour of laying before this Association to the consideration of the proximate cause of death when air is introduced spontaneously into the circulating system; that is to say, when it is not purposely injected into the heart, but when it gains admittance into that organ either in consequence of one of the large veins in its vicinity being opened at a point where the flux and reflux of the blood are naturally observed, or, during operations, under such circumstances, whether of disease of the coats of the vessel, of traction in the removal of tumours, or of contraction of surrounding muscles, that it forms an unyielding, uncollapsing tube, into which the air is apt to be sucked in order to supply the vacuum, which the action of inspiration has a tendency to occasion within the thorax.

The inquiry into the cause of death consequent upon the spontaneous introduction of air into the venous system is not a purely physiological question, but is of peculiar interest to the practical surgeon, as the mode of treatment to be adopted in those cases of operation or injury in which this unfortunate accident has happened must necessarily depend upon the cause of the occurrence of that fatal event, which it is our object to avert. That this question cannot be considered as having, as yet, been definitely answered, is obvious from the fact, that, within the last year, two theories, altogether opposed to one another, have been published by MM. Mercier and Marchal de Calvi respectively. These will be considered in a subsequent part of this paper. Before proceeding further, however, it may be as well to take in review the opinions of some of the principal writers on this subject.

Bichat* supposed that death was occasioned by the irritation produced by the air whilst circulating through the vessels of the brain. In support of this opinion he states, 1*st*, That the heart beats for some time after all animal life has ceased, and that it is even increased in activity, driving the frothy blood with much force through the lungs and arterial system; 2*dly*, That, by direct experiment, viz. forcing air into the carotid arteries, death may be occasioned; 3*d*, That Morgagni and others relate cases of gaseous apoplexy, (as they are called,) in which the only lesion found is the presence of air in the cerebral vessels. Nysten† was of opinion that the over-distension of the pulmonic ventricle occasioned such a dragging of the fibres of the aortic ventricle as to oppose the free exercise of its contractility;—Dupuytren, that the air having arrived at the right auricle, becomes dilated, distends that cavity, opposes itself to its contractions, and thus stops the circulation;—MM. Piedagnel‡ and Leroy§ that the air, driven

* Recherches sur la Vie et la Mort, pp. 208–212.
† Recherches de Physiologie et de Chimie Pathologiques.
‡ Recherches sur l'emphyseme du Poumon Journ. de Physiologie, 1829.
§ Archives Générales de Médecine, 1823.

by the contractions of the right ventricle, acquires, by the change of temperature, a sudden expansion, distends the capillaries of the lungs, which organs become emphysematous, and that thus the circulation ceases. Amussat* supposes death to be the result of the distension of the right cavities of the heart. Bouillaud† regards the proximate cause of death as threefold, 1*st*, as occurring from enormous distension of the right cavities of the heart, the air being expanded by the heat of the blood, and, consequently, impeding the contractions of that organ; 2*d*, from the presence of spurious blood in the branches of the pulmonary artery, preventing the free passage of the blood through the lungs; 3*d*, from air entering the vessels of the brain, and thus compressing that organ. Dr Cormack‡ is of opinion that the deleterious effects resulting from the entrance of air during operations are purely mechanical, and that the death of the patient depends simply upon the contractions of the right side of the heart being arrested or greatly impeded in consequence of the presence of the elastic fluid. In an able article in Dr Forbes's Journal§ on the introduction of air into the veins, the reviewer says, "with regard to the second cause adduced by Bouillaud we are disposed to think that it has been too much overlooked. The degree in which its operation will be conceded, however, must depend upon the views entertained of the physiology of the circulation. If we believe (as we think we are not only warranted but compelled to do) that the changes which the blood undergoes in the capillaries, both of the lungs and of the general system, are necessary for the creation of a part of the motive power of the circulation, it is obvious, that, if these be stopped in any way, a check must also be put to the movements of the fluid. In asphyxia we cannot doubt that the obstruction of the circulation commences in the lungs, in consequence of the deficient supply of oxygen preventing the due aeration of the blood, and that paralysis of the right ventricle, from over-distension, and of the left, from want of its required stimulus, are but results of this primary cause. Now, when death takes place rapidly from the forcible infiltration of air into the veins, it is easy to perceive how the distension of the right ventricle, and the consequent stoppage of the circulation, are the immediate results of the process. But when air has spontaneously entered, and is found to have passed into the pulmonary artery, it does not seem unreasonable to suppose that it may prevent the passage of the blood with which it is mixed through the lungs,—the due relation between the blood in the vessels and the air in the cells being just as much disturbed by the admixture of air." Marchal

* Recherches sur l'Introduction de l'Air, &c. pp. 240.
† Gazette Medicale, 1838. ‡ Thesis, 1837.
§ British and Foreign Medical Review, Vol. vi.

de Calvi* attributes the sudden death in these cases to the operation of a poisonous agent. He is of opinion that carbonic acid is disengaged from the venous blood by the oxygen of the air that is mixed with it, and that this operates as a poison upon the heart. In confirmation of this he says, that, if expired air be blown into the veins of an animal, it is more rapidly fatal than pure atmospheric air. Lastly, Mercier† supposes that death occurs in the cases under consideration, as in prolonged syncopes; the brain not receiving the blood, which is necessary for the exercise of its functions, and that, as in syncope, death is only apparent, and becomes real by the arrest of the heart's action; so death, from the introduction of air into the veins, only becomes real, because the course of the blood is interrupted for too long a time. The air preventing the passage of the blood from the arterial into the venous system in three ways, 1*st*, by its elasticity; 2*dly*, by its reflux; and 3*d*, by its admixture with the blood. These causes, says M. Mercier, prevent a due supply of blood to the left ventricle, and the small quantity that does reach that cavity being distributed through the arterial system generally, does not arrive at the brain in sufficient quantity to afford that organ its necessary stimulation. The curative indications that he deduces from these opinions will be adverted to in a subsequent part of this paper.

Having thus given a short abstract of the principal opinions that have been advanced in explanation of the occurrence of death after the introduction of air into the venous system, I think it will be found, on a closer examination into the facts on which they are founded, that not one of them is sufficiently free from objection to allow us to receive it as a perfectly satisfactory explanation of the proximate cause of death in these cases. In order to facilitate their analyses, and to avoid repetition whilst discussing them, we will arrange these opinions in four classes, viz.

1*st*, That death ensues from over-distension of the right cavities of the heart. Of this opinion are Nysten, Dupuytren, Cormack, Amussat, and Bouillaud (partly.)

2*d*, That death ensues from the irritation occasioned by the passage of the air through the vessels of the brain.—Bichat.

3*d*, That the heart's action is arrested in consequence of the deleterious influence of the carbonic acid which is eliminated from the venous blood.—Marchal de Calvi.

4*th*, That the circulation is arrested in the lungs, either, as Piedagnel and Leroy have supposed, in consequence of these organs becoming emphysematous, or, as Bouillaud and Mercier, (partly) think from obstruction of their capillaries, or, as the reviewer in Dr Forbes's Journal is of opinion, in consequence of the respiratory changes being interfered with.

* Annales de Chirurgie, Vol. vi. † Gazette des Hopitaux, Dec. 3d 1842.

With regard to the first of these opinions it will be shown in a subsequent part of this paper, that overdistension of the right cavities of the heart cannot and does not take place when air is spontaneously introduced into the veins, although there can be no doubt that, if it be forcibly blown into them or injected by means of a large syringe, as in the experiments of Nysten and of Cormack, the pulmonic cavities of the heart may become so distended, as that their action may be mechanically interfered with. I think, however, that it admits of doubt whether, in any case even of forcible introduction of air, this distension can take place to such an extent as to be sufficient of *itself* to arrest the heart's action.

There have been various opinions entertained with regard to the manner in which this alleged overdistension is produced. By some it has been supposed that the increase of temperature which the air might acquire by mixing with the blood, would cause such an increase in its bulk as might occasion the distension of the cavities of the heart. But, as a given quantity of air only expands by the $\frac{1}{480}$th of the volume it occupies at 32° Fahrenheit for every degree of heat it receives, it becomes obvious that the expansion of air in passing from the temperature of the atmosphere, say 60° Fahrenheit to that of venous blood, 100° Fahrenheit, would not amount to more than the $\frac{1}{12}$th of its bulk,—too trifling an increase to be of any moment.

By others it has been supposed that, during the diastole of the right cavities, the expansion of the air which has been compressed by their systole might occasion such a degree of distension as would be incompatible with their action. But air can only be compressed in an air-tight cavity, which the right ventricle is not, the tricuspid valve not shutting sufficiently closely to prevent the reflux into the dilated auricle of a certain quantity of that spumous fluid with which the ventricle is filled; as may readily be seen by laying open, (before the heart's action has ceased,) the chest of a dog that has been killed by the introduction of air into its veins. But even if the tricuspid valve could shut sufficiently closely to prevent all regurgitation, as the compressive force of the right ventricle would probably not be equal to more than about the 1.15th of the pressure of the atmosphere, as will hereafter be shown, but a very trifling influence would be exerted on the contained air.

Granting, however, that, in cases in which air is forcibly injected, the heart becomes overdistended, will that condition be, of itself, sufficient to occasion death, or must we look to some other cause for the occurrence of that event? The heart has, in these cases, been compared to a bladder, that is overdistended in consequence of retention of urine, and which, as is well known, cannot, when its fibres are stretched beyond a certain point, contract upon

its contents. But does the analogy on closer examination hold good? Is there not this most important difference between the two cases that in the one (that of the bladder) the distension is gradual, whilst in the other (that of the heart) it is sudden. Now the *sudden* introduction of a liquid into the bladder, as when water is injected during the sounding for stone, or previous to the performance of lithotrity, will act as a stimulus to that organ, causing it, if the injection be pushed to distension of it, to contract forcibly upon its contents.

The same effect is produced in the heart. If a small quantity of tepid water be injected into the right cavities of the heart, so as to distend them, immediately after the death of the animal whilst it is still in action, that organ will be observed to contract much more forcibly than before, indeed in a convulsive manner; this is in accordance with the observation of Bichat, which observation I have had frequent occasion to confirm, that the action of the heart is increased in activity after the introduction of air into its cavities. From this, then, it would appear that the fibres of hollow muscles have a tendency to be called into more forcible action rather than to be paralyzed on a sudden attempt being made to distend them, although the opposite may be the case when the distending cause is gradually applied; and as the heart, in particular, seems to be stimulated to increased activity by the presence of air in its cavities, it admits of question whether a sudden distension of the right auricle and ventricle would, of itself, be able to occasion the arrest of the heart's action, or whether this event be not rather referable to other causes that will presently be adverted to.

Before proceeding to the consideration of the question, whether overdistension of the right cavities of the heart does or does not take place when air is spontaneously introduced into the veins, it will be better to give a short description of the phenomena that ensue on the occurrence of such an accident. When a vein at the root of a dog's neck is opened, at a point where the flux and reflux of the blood are perceptible, the air will be observed to enter, at the first inspiratory effort, with a lapping or gurgling sound, expressively called by the French a "*glou glou*," the variety of sound depending upon the size and situation of the opening. The entrance of the air is immediately followed by a struggle, during the deep inspirations succeeding which, fresh quantities of air gain admittance; the entry of each portion being attended by the peculiar sound above described. On listening now to the action of the heart, a loud *churning* noise will be heard, synchronous with the ventricular systole, and the hand will, if applied to the parietes of the chest, perceive at the same time a peculiar bubbling, thrilling, or rasping sensation, occasion-

ed by the air and blood being, as it were, whipped together between the *columnæ carneæ* and *cordæ tendineæ*. As the introduction of air continues, the circulation becomes gradually more feeble and languid, the heart's action, however, being fully as forcible, if not more so, than natural. The animal soon becomes unable to stand, if placed upon its feet rolls over on one side, utters a few plaintive cries, is convulsed, extrudes the feces and urine, and dies. If the thorax be immediately opened, it will be seen that the heart's action is continuing regularly and forcibly, and that the pulmonic cavities, though filled, do not appear distended beyond their ordinary size. The detail of the following experiment will illustrate these points.

The left jugular vein having been exposed in a young puppy, puncture was made in it at a point where the venous pulse was perceptible. Air immediately rushed into the heart, with a liquid hissing sound; the animal then became convulsed, and struggled violently. On listening to the thorax the heart could be heard to beat very forcibly, with a loud churning noise; and a peculiar rasping thrill was perceptible on applying the hand to the parietes of the chest. The air entered at each inspiration, and frothy blood issued from the opening in the vein at each expiration; convulsive movements and deep gaspings ensued, and at each spasmodic action of the muscles of the trunk air was forced out in the form of a bloody froth, whilst at each gasp a fresh quantity gained admittance.

Ninth minute after death. All movement having ceased, the chest was laid open. The heart is beating from 60 to 68 strokes per minute, regularly and forcibly. The ventricles are not fuller than usual, the right auricle is distended with a florid bloody froth, the bubbles of which can be seen distinctly through its parietes. The left auricle is contracted upon itself. At each auricular contraction a quantity of bloody froth can be seen to be forced into the *venæ cavæ*, whence it flows again into the auricle during the diastole of that cavity. Air-bubbles can also be seen through a thin part of the right ventricle near the septum. The *venæ cavæ*, both superior and inferior, are full of large bubbles of bloody froth, which at each systole and diastole of the auricle make a corresponding movement of flux and reflux. The pulmonary artery and coronary veins appear of a lighter colour than usual, evidently from containing less blood. The lungs are very pale, certainly not collapsed, perhaps slightly distended. The pulmonary veins contain but very little blood indeed.

Fourteenth minute after death. The right auricle contracts from 60 to 64 times per minute; the ventricles from 30 to 34. The state of the left auricle could not be observed.

Twenty-first minute after death. The contractions of the ventricles having gradually become more and more slow do not amount to more than six per minute. The contractions of the left auricle have ceased; but the right auricle beats regularly and forcibly about 60 times per minute.

Fifty-sixth minute after death. The right auricle is still contracting about 30 times in a minute. There is an occasional tremulous contractile movement in the ventricles.

Sixty-sixth minute after death. Right auricle contracting about 20 times per minute. The movement of flux and reflux continues in the *venæ cavæ* synchronously with the contractions and dilatations of the auricle. Now and then an irregular contractile movement in the ventricles.

Eighty-sixth minute after death. Right auricle still contracting at times, about 6 or 8 per minute : ventricles perfectly quiet. Experiment discontinued.

On examining the organ of the circulation a large quantity of bloody froth was found in the right cavities of the heart, the *venæ cavæ* and the pulmonary artery. There was no fluid blood in any of these. The left cavities of the heart were contracted upon themselves and contained a very small quantity of black blood; there were no air-bubbles found in the arterial system. The pulmonary veins were nearly empty, containing only a few drops of dark blood. The lungs were very pale and bloodless, and in a mid-state between collapse and distension. I have repeated this experiment many times, and in no one instance have I found the right cavities of the heart distended with the bloody froth, certainly by no means so full as they usually are in cases of death from asphyxia. This is in accordance with the observation of Barthelemy, who states that he has found the heart, after death from the spontaneous introduction of air into the veins, flabby, pliant, and collapsed ; and, indeed, as has already been said, the imperfect closure of the tricuspid valve, allowing at each contraction of the ventricle a reflux of the bloody froth into the right auricle, whence at the auricular systole it is partly drawn into the cavæ, will, by acting as a safety valve, effectually prevent so mobile a fluid as air from accumulating in the ventricle to such a degree as to overdistend it.

But, independently of the anatomical characters, which are of themselves sufficient to show that death cannot occur from arrest of the circulation in consequence of any overdistension of the right cavities of the heart interfering mechanically with the action of that organ, it can be demonstrated beyond doubt that death does not take place in the heart at all ; that event invariably occurring before the contractions of that organ have ceased. That the heart's action continues uninterruptedly long after respiration

has been arrested, and after the eyelids have ceased to contract on the application of a stimulus to the eyeball—after animal life is entirely extinct—can readily be ascertained by any one who will examine an animal killed by the spontaneous introduction of air into its veins. And that this action of the heart is not confined to merely a few irregular beats, but continues for some considerable time, may be seen by the following analysis of five experiments in which the contractions of this organ were carefully watched and noted.

Expt. 1. Death in nine minutes; action of heart 60 to 68 per minute.

Fifth minute after death. Right auricle 60 to 64; ventricles 30 to 34

Twelfth minute after death. Right auricle 60; ventricles about 6; left auricle has ceased acting.

Forty-seventh minute after death. Right auricle about 30; occasional tremulous movements in ventricles.

Fifty-seventh minute after death. Right auricle about 20; ventricles as before.

Seventy-seventh minute after death. Right auricle feebly and irregularly 6 or 8; ventricles still.

Expt. 2. Death in twenty-one minutes; contractions of heart, 88 to 90.

Fifth minute after death. Right auricle 90 to 94; tremulous movements, with a few irregular contractions in the ventricles.

Eleventh minute after death. Right auricle about 80; twitching movements, but no regular contractions in the ventricles; left auricle has ceased.

Twentieth minute after death. Right auricle 20 to 24; tremulous movements in ventricles.

Twenty-fifth minute after death. Right auricle ceased.

Expt. 3. Death in fifteen and one-half minutes; contractions of ventricles about 100; auricles acting still more rapidly.

Sixth minute after death. Right auricle 96 to 100; left auricle has ceased; regular contractions of the ventricles replaced by irregular contractile movements.

Ninth minute after death. Right auricle 80; ventricles as before.

Fourteenth minute after death. Right auricle about 60; ventricles nearly still.

Nineteenth minute after death. Right auricle about 56; ventricles quite still.

Twenty-seventh minute after death. Right auricle ceased.

Expt. 4. Death in twenty-six minutes; ventricles from 50 to 60; auricles move rapidly.

Sixth minute after death. Right auricle 80 to 88; left auricle has ceased; tremulous movements in ventricles.

Tenth minute after death. Right auricle 40, very irregularly; ventricles usually still.

Nineteenth minute after death. Right auricle about 20; tremulous contractile movements in ventricles. Experiment discontinued.

Expt. 5. Death in ten minutes; heart beating from 80 to 90.

Sixth minute after death. Left auricle ceased.

Seventh minute after death. Right auricle about 60; ventricular contractions somewhat tremulous.

Tenth minute after death. Right auricle about 50; contractions of ventricles slower and more tremulous.

Fifteenth minute after death. Right auricle 40 to 46; ventricular contractions have been replaced by irregular tremulous movements. Experiment discontinued.

From these observations, then, it is evident that the right cavities are not prevented from acting in consequence of overdistension, which, in reality, does not exist, or from the operation of any other local cause, but that the heart continues to beat for a very considerable length of time after respiration and the phenomena of animal life have ceased; and that, consequently, the cause of death cannot reside in that organ, but must be looked for somewhere else.

The second opinion, that death is dependent upon the irritation produced by the presence of air in the vessels of the brain, appears to be equally inconsistent with fact; and may be dismissed with the remark, that air is never found in the cerebral vessels of some animals, such as dogs and rabbits, that have been killed by its spontaneous introduction into the veins, and but very seldom in some others, as sheep and horses; in which animals alone, of those that have been experimented upon, is the elastic fluid ever met with, as Amussat and others have shown, in the left cavities of the heart and the arterial system, and in them but in very small quantity.

In answer to the third opinion, that of Marchal de Calvi, that when atmospheric air is mixed with the venous blood in the right side of the heart, the carbonic acid that is eliminated exercises a poisonous influence on that viscus, it will scarcely be necessary to adduce any formal experimental refutation, as it has already been stated more than once in the course of this paper, that death cannot commence in the heart, that organ being in full activity after respiration has entirely ceased. Were, however, direct proof wanted to show that the elimination of carbonic acid, admitting it to take place in the right cavities of the heart, would exert no direct deleterious influence on that viscus, the experiments of Nysten on the injection of that gas into the veins would afford it. He says, "carbonic acid, even where the product of putrified animal matters, when injected into the venous system in considerable quantity, but

with the precautions necessary to avoid distension of the pulmonary heart, does not produce any other consecutive phenomenon beyond a muscular weakness, which ceases in a few days." * The only argument adduced by Marchal de Calvi in support of his opinion is, that the action of the heart is arrested sooner by expired than by pure atmospheric air. The reason of this difference is, no doubt, that one is blown in, whilst the other gains admittance slowly and spontaneously. The rapidity of death being invariably in the direct ratio of the rapidity and force with which the air is introduced.

We now come to the consideration of the fourth class of opinions, viz. that death is occasioned by the arrest of the circulation in the lungs. It has been shown that death does not occur from overdistension of the right auricle or ventricle, or from the noxious influence on the heart of the carbonic acid, eliminated from the venous blood, or indeed from any cause that affects that organ primarily; nor is it occasioned by the irritation of the air on the brain. There will now, I think, be but little difficulty in proving that the primary cause of the fatal event is the arrest of the blood in the capillaries of the lungs, the consequence of which is that an insufficient quantity is sent to the nervous centres, the due performance of whose functions is necessary for the maintenance of respiration and animal life.

The effect of the injection of certain substances, such as mercury, oil, or purulent matter into the veins, resembles very closely that of air. Death in these cases ensuing either very shortly after the foreign matter has gained admittance into the venous system, in consequence of its being unable to pass through the capillaries of the lungs, and thus arresting the general circulation; or else, if the animal survive the immediate effects of the experiment, it will probably die in a few days of pneumonia; which disease, as Nysten has shown, is very apt to supervene in those dogs that are not immediately killed by injecting air into their veins. The anatomical evidence in support of the opinion that the presence of air in the capillaries of the lungs arrests the circulation through these organs, will be found in the fact, that, although the right cavities may be full of bloody froth, it is very seldom met with in the left side of the heart, or if so, but in very small quantity, merely a few stray bubbles,—in the pulmonary artery being, as far as it can be traced, filled with bloody froth,—in the lungs being always in an exsanguine condition,—and in the pulmonary veins and left side of the heart, and arterial system, being nearly, if not entirely empty of blood, whilst the venous system is gorged as far as the *venæ cavæ* or right auricle, where the presence of air prevents the farther entry of blood. From the analogy, then, afforded by

* Recherches de Physiologique, &c., pp. 93.

the injection of other foreign matters into the veins, and from the *post mortem* evidence afforded by the venous system, and the condition of the heart and lungs, we are, I think, warranted in concluding that the primary arrest of the circulation takes place in the pulmonic capillaries, or in the terminal branches of the pulmonary artery.

The next question that presents itself is the manner in which this arrest is effected. Are we to suppose with MM. Piedagnel and Leroy, that it is owing to the occurrence of emphysema of the lungs, or, that it is the consequence of the due relation between the air in the cells and the blood in the vessels of these organs being disturbed, or, that it is merely the result of a mechanical obstacle afforded by the presence of air in the pulmonary vessels?

With regard to the first of these opinions, there is certainly no proof that emphysema of the lungs takes place, in, at least, the majority of the cases under consideration. There can be no doubt that the lungs are always found pale and bloodless in animals that have been killed by the introduction of air into their veins, but this is rather owing to the absence of blood in the pulmonary veins, and to the presence of a sanguineous froth in the branches of the pulmonary artery, than to any real emphysematous condition of the tissue of these organs. The air-cells of dogs, moreover, are naturally large; hence the lungs of these animals might be considered, by persons only accustomed to look at those of the human subject, to be emphysematous, when in reality they are in their natural condition.

In reference to the next opinion, that the due performance of the changes of the blood in the lungs are necessary for the creation of a part of the motive power of the circulation, and that if these be stopped, a check must be put to the movement of the fluid, it would be leading us too much away from our subject to enter into a consideration of this question, which, notwithstanding the high authority by which it is supported, appears to me to be far from determined in the affirmative. It may therefore be sufficient to state, that the arrest of the circulation in the cases under consideration can be explained without having recourse to this supposition.

We now arrive at the consideration of the effect that the presence of frothy blood, or rather of a bloody froth, in the branches of the pulmonary artery, would have in checking the circulation through the lungs, and, as a necessary result of this, through the system generally. It has already been stated that, on opening the chest of an animal that has been killed by the spontaneous introduction of air into its veins, we shall find the right cavities of the heart and the pulmonary artery filled with a bloody froth, resem-

bling very closely the albumen of an egg, coloured pink and whipped up; the air and blood being, by the contractions of the heart, beaten up so intimately, that neither is perceptible in a separate state. Now it needs but very little proof to show that such a mixture as this will offer a considerable degree of resistance to the passage of blood through the capillary vessels of the lungs.

It is well known to all natural philosophers that the presence of bubbles of air in capillary tubes retards the passage of liquids through them; each bubble acting as a damper, and lessening or even destroying, by its elastic reaction, the momentum of the liquid. That the presence of air-bubbles in the capillaries of the lungs does in reality offer an obstacle to the passage of the blood through the vascular system of these organs, may be proved by the following experiment. Let a pipe be fixed in the pulmonary artery of a dog recently killed, to which a syringe, with a hæmadynamometer adapted to it, should be attached, so that the force with which fluid is injected may be measured, it will now be found that it requires but a pressure of from $1\frac{1}{2}$ to 2 inches of mercury to drive beat bullock's blood through the capillaries of the lungs, so that it may flow in a free stream from the left auricle, or from a pulmonary vein that has been opened. I have indeed seen it flow through with a pressure somewhat below $1\frac{1}{2}$ inches of mercury, and this without any extravasation taking place into the tissue of the lung. Now, if the syringe be detached, and air blown into the pulmonary artery, it will be found that it requires a pressure of from 3 to $3\frac{1}{2}$ inches of mercury to force the beat blood through the same set of vessels. Thus the presence of air within the pulmonic capillaries requires the propulsive power necessary to force blood through them to be nearly doubled. That this is not owing to any peculiar condition induced in the capillaries, but is dependent on the mechanical obstacle afforded by the presence of air in them, is proved by the fact, that as soon as the resistance of the air is overcome, and that fluid driven out of the vessels, a pressure, as in the former case, of from $1\frac{1}{2}$ to 2 inches of mercury, will be fully sufficient to maintain the flow of the blood through the lungs. This experiment appears to me to be conclusive of the fact, that the presence of air in the capillaries of the lungs offer a mechanical obstacle to the passage of fluids through these vessels, which obstacle is in the living body, probably too great for the right ventricle to overcome.*

* It would be exceedingly difficult, if not impossible, to prove the amount of propulsive power exerted by the right ventricle, as the experiment of attaching a hæmadynamometer to the pulmonary artery of a living animal, would be attended by so many modifying circumstances as not to admit of any conclusive result being obtained. If, however, we are allowed to assume that a muscle contracts with a power proportioned to its size, we shall, as the thickness of the walls of the right ventricle are to those of the left, according to Bouillaud, as $2\frac{1}{4}$ to 7, be allowed to estimate

From what has already been stated with regard to the force that is required to overcome the obstacle that air creates to the passage of blood through the capillaries of the lungs, it is evident that an increase of power in the heart's action would be necessary in order to accomplish this. But, in point of fact, so far from exerting an increased power, the heart exercises scarcely any propulsive influence upon the frothy mixture that has gained admittance into the right ventricle; which is partly driven, at each contraction, backwards through the tricuspid valve and auricle into the *venæ cavæ*, as well as forwards into the pulmonary artery. As the circulation through the lungs becomes more and more impeded, the quantity of blood sent to the left cavities and thence through the coronary arteries to the muscular substance of the heart is proportionally lessened; hence, coincident with the obstruction in the pulmonic capillaries, there is a failure in the power of the heart's action, which renders it less able to overcome the very obstacle that has occasioned it. The quantity of blood sent to the left side thus becoming gradually less and less, until at last it is insufficient to carry on the actions of animal life, when death necessarily ensues. The respiratory movements no doubt ceasing, in consequence of the absence of a proper supply of arterial blood to the nervous centres, preventing the impression of those sensations which are necessary for the due performance of the act of respiration.

The series of phenomena, then, that take place when air is introduced spontaneously into a vein at a point where the flux and reflux of the blood are observable, or within that circle in which the action of respiration is felt, are as follows:—At the first inspiratory effort a quantity of air rushes into the right auricle, where it becomes mixed with the blood. As this cavity contracts at the same moment that the ventricle dilates, a large portion of the air passes into the ventricle, where it is, by the action of the *cordæ tendineæ* and *columneæ carneæ*, beaten up with the blood, the remainder is forced back into the *venæ cavæ*. The ventricle then contracting as the auricle dilates, its contents have a natural tendency to be driven onwards into the pulmonary artery, but this they can only do effectually, that is to say, be forced on with the full power of the ventricle, by having a point of support in the tri-

the power of its contractions in the same ratio. Now, as the left ventricle propels the blood in the arterial system with a pressure equal, on an average, to about five inches of mercury, if anything rather less, certainly not more, the ratio of the pressure exercised by the left ventricle, as compared to that of the right, may be stated by the formula 7 : 2.5 : : 5 : 1.78, which would probably be about the pressure in the pulmonary artery, and which agrees with the force that is required to propel bullock's blood through the vessels of the lungs. But, as it has already been shown that it requires a pressure of from 3 to 3½ inches of mercury to force blood through the pulmonic capillaries, after air has been blown into them, a moving power of less than 2 inches would clearly be unable to overcome such an obstacle, and hence arrest of the circulation must necessarily ensue.

cuspid valve from which to react; but as this valve does not close so completely as to prevent the reflux of a certain quantity of air, regurgitation into the auricle necessarily takes place, which cavity, contracting again, forces the bloody froth into the right ventricle. And thus the same series of phenomena is repeated over and over again, until the capillaries of the lungs becoming more and more obstructed, the quantity of blood sent through them becomes gradually too small to afford a due stimulus to the nervous centres. Hence a kind of syncope is induced similar to what takes place in those cases in which, from any cause, whether profuse hemorrhage or ligature of the carotid and compression of the vertebral arteries, as in Sir Astley Cooper's experiments, an insufficient supply of blood is sent to the brain. The functional activity of the nervous centres being thus depressed, the respiratory movements cease from want of sufficient maintaining power, and animal life becomes extinguished; the contractions of the heart gradually ceasing in consequence of the want of its necessary stimulus,—the blood.

The arrest, then, to the passage of the blood takes place in the capillaries of the lungs or in the terminal branches of the pulmonary artery, in consequence of their becoming obstructed by the air-bubbles. The right auricle and ventricle then become filled with a spumous fluid, which they can neither propel forwards nor drive back to any material extent; but which, oscillating in the large veins about the heart, acts as a mechanical obstacle to the passage of the blood through them. Hence the animal dies as if a ligature were thrown round the superior and inferior cava, and we accordingly find, on examining the bodies of those animals killed by the spontaneous introduction of air into their veins, the same congestion in the venous and absence of blood in the arterial system, that would result from such an operation. From what has been stated, then, in the preceding pages, I think we may conclude;

1*st*, That the primary arrest of the circulation takes place in the capillaries of the lungs, or in the terminal branches of the pulmonary artery, in consequence of inability in the right ventricle to overcome the mechanical obstacle presented by air-bubbles in the vessels of those organs.

2*d*, That respiration and animal life cease in consequence of a deficient supply of arterial blood to the central organs of the nervous system.

Having thus attempted to determine the proximate cause of death after the introduction of air into the veins, we shall now consider the plan of treatment that it is most advisable to employ, not only in warding off a fatal result after air has been introduced into the vessels during operations, but also in preventing, if possible, the occurrence of this accident.

And first of all, as most important, let us take into consideration the best way of preventing the occurrence of the accident in question. Before doing so, however, it may be better, in order to understand the principles on which we should act, to give a brief summary of those circumstances that are peculiarly apt to occasion the introduction of air into the circulating system during operations. Now it is well known that what is called by the French writers the "canalization" of a vein, or its conversion into a rigid uncollapsing tube, is the condition of all others which is most favourable to the introduction of the air into it. Indeed, except in those situations in which there is a natural movement of flux and reflux of the blood in the veins, this accident cannot occur unless these vessels be canalized, or, in other words, prevented from collapsing. This canalization of the vessel may be occasioned in a variety of ways. Either the cut vein may be surrounded by indurated cellular tissue, which will not allow it to retract upon itself, but keeps it open like the hepatic veins; or the coats of the vessel may have acquired, as a consequence of inflammation or hypertrophy, such a degree of thickness as to prevent their falling together when divided. Again, the principal veins at the root of the neck have, as Bérard has pointed out, such intimate connections with the neighbouring aponeurotic structures that they are constantly kept in a state of tension, so that their sides are held apart when they are cut across. The contractions of the platysma and other muscles of the neck may likewise, as Mr Shaw has shown, have a similar effect. In removing a tumour also that is situated about the neck, the traction exerted upon its pedicle may, if this contain a vein, cause it to become temporarily canalized; and the incomplete section of the vessel, especially in a transverse direction, must necessarily prevent the approximation of the sides of the incision in it, which will be rendered open and gaping by the retraction of the surrounding tissues. This patency in the incision in the vein is apt to be increased by the position that is necessarily given to the head and arm in all operations of any magnitude about the shoulders and neck. Lastly, the introduction of air into a vein will be favoured by the vessel being divided in the angle of a wound, the vein being, when the flaps that form that angle are lifted up, rendered open-mouthed and gaping.

On looking over the reports of cases in which air gained admittance into the veins during operations, it will be found that these vessels were always in one or other of the above-mentioned conditions. Thus in Beauchesne's* case, air was introduced in consequence of incomplete division of the external jugular immediately above the right subclavian, whilst in a state of tension during the removal of a portion of the clavicle. In a case that occurred to

* Journal de Physiologie, Tome ix. pp. 80.

Dupuytren* a large vein connected with the tumour and communicating with the jugular, was cut at the last stroke of the scalpel, whilst the tumour was being forcibly drawn up. The vein was found to be adherent to the sides of a sulcus, so that it remained gaping when cut. In a case by Delpech† there was hypertrophy of the axillary vein causing it to gape like an artery. In Castara's‡ case there was incomplete section of a vein, which opened into the subscapular, whilst the tumour was being raised up. In Roux's § a vein in the neck was opened, whilst a tumour, which was being removed from that region, was being forcibly raised, in order to dissect under it. Ulrick‖ saw the accident occur in consequence of the incomplete division of the internal jugular vein which was implicated in a tumour in the neck. A similar case happened to Mirault¶ of Angers, the internal jugular being divided to half its extent. A case occurred to Warren** in which the air entered by the subscapular vein, the coats of which were healthy but in a state of tension, in consequence of the position of the arm ; and another in which the same accident happened from the division of a small transverse branch of communication between the external and internal jugular, whilst in a state of tension. Mott,†† whilst removing a tumour of the parotid gland, opened the facial vein, which was in a state of tension in consequence of the position of the patient's head, when air was introduced. A case is related by Malgaigne,‡‡ in which the accident happened in consequence of the incomplete section of the external jugular vein, which was enveloped in a tumour that was being removed. M. Bégin§§ also relates a case in which this accident happened in consequence of the puncture of the internal jugular whilst he was removing a tumour from the neck.

These cases, which are all that I have been able to meet with, in which the condition of the wounded vein was particularized, show clearly, what is the state of the vessel and of the surrounding parts that is most likely to favour the occurrence of the accident, and consequently, what the surgeon should peculiarly guard against in the removal of tumours about the neck and shoulders, viz. incomplete division of the veins and the employment of forcible traction on the diseased mass at the moment of using the scalpel. I am aware that, in removing tumours from the neck and shoulder, it is in many cases impossible to avoid drawing them forcibly upwards or forwards, in order to get at their deeper at-

* Archives Générales de Medecine, Tome v. pp. 430.
† Memorial des Hôpitaux du Midi, 1830.
‡ Saucerotte. Thesis. § Journal Hebdomadaire, Tome ii. pp. 165.
‖ Journal des Connaissances Med. Chirur., 1834. ¶ Gueretin, Thesis, 1837.
** Gazette Medicale, 1833 ; and Warren on Tumours.
†† Gazette Medicale, 1831. ‡‡ Ibid. 1836.
§§ Presse Medicale, 1837.

tachments; but if this be necessary the chest should, for reasons that will immediately be pointed out, be tightly compressed, so that no deep inspirations may be made at the moment that the knife is being used, or before a divided or wounded vein can be effectually secured.

But although it be necessary for the spontaneous introduction of air into the circulating system, that the vein be either canalized in one or other of the ways that has just been mentioned, or else that it be opened where the venous pulse exists, yet it is only during the act of inspiration that air can gain admittance into the vessel; and it is the more ready to do this the deeper the inspiratory efforts are. If a vein be opened at the root of a dog's neck, it will be found that it is only during inspiration that air rushes in; that none gains admittance during expiration, and but little, if any, when the inspirations are shallow, as when the chest is forcibly compressed by the hands; and that the rapidity of the spontaneous introduction of air is, *cæteris paribus*, in proportion to the depth of the inspirations. This is in accordance with the experiments of Dr Carson and Sir David Barry on the influence of the respiration on the circulation of the blood, and depends upon the tendency that there is to the formation of a vacuum within the thorax, more particularly in the pericardium, during inspiration; at which time the blood is carried with increased velocity along the veins in the neighbourhood of the heart; and when expiration takes place a temporary retardation occurs. This is particularly evident during excited respiration. Now, during operations the state of the breathing is such as to dispose the patient peculiarly to the entrance of air into the veins. When a patient is under the knife, the respirations are generally shallow and restrained, the breath being held, whilst every now and then there is a deep gasping inspiration, at which moment, if a vein be opened in which the pulse is perceptible, or that is canalized, air must necessarily be sucked in; and, as has already been said, in quantity and force proportioned to the depth of the inspiration. This, then, being the case, the mode of guarding against the introduction of air into the veins is obvious. The chest and abdomen should be so tightly bandaged with broad flannel rollers or laced napkins, as to prevent the deep gasping inspirations, and to keep the breathing as shallow as possible, consistently with the comfort of the patient. I have often found, as has already been stated, that the entrance of air into the veins of a dog could be arrested by forcibly compressing the chest of the animal so as to confine the respiratory movements, but that as soon as a deep inspiratory effort was made, the compression having been removed, a rush of air took place into the vessel. If, therefore, during an operation about the root of the neck or summit of the thorax, the chest be bandaged, as here recommended, the surgeon must be careful not to remove

the compression until the operation be completed and the wound dressed, for if this precaution be not attended to, as the patient will most probably, on the bandage being loosened, make a deep inspiration, air may be sucked in at the very moment that all appeared safe.

If compression of the chest did not altogether prevent the entry of air into a wounded vein, it would at all events tend to lessen its quantity, as well as the rapidity and force with which it would rush in; which will always be found to be proportioned to the depth of the inspirations. Thus a very material point would be gained; for it has been fully proved from the experiments of Nysten, Cormack, and Amussat, as well as from recorded cases of recovery in man,* that it is necessary that a certain quantity of air be introduced before death can take place, in confirmation of the observations made long since by Nysten, that a few bubbles of air would not occasion death. Magendie, states that he has several times, whilst injecting medicinal saline solutions into the veins of patients, seen air introduced without any bad consequences ensuing. In order, then, that the accident prove fatal, it is necessary that a certain quantity of air be introduced into the venous system. This quantity it is impossible to determine accurately, for obvious reasons; but it may probably be stated as being equal to so much as will obstruct the pulmonic capillaries to such an extent, as that a sufficient quantity of blood to support life does not pass through the lungs. If, therefore, in the event of not being able to prevent the entry of some air into the venous system, we can keep the quantity introduced below this, we should be able to avert a fatal termination.

Different plans have been recommended by surgeons for the treatment of those cases in which air has already gained admittance into a vein; but, from the very fatal nature of this accident, it does not appear that much benefit has resulted from any of them. The recovery of the patient in some of the cases appearing to be rather due to the quantity of air that was introduced

* I may mention the following case in proof of the fact that a moderate quantity of air may be introduced into the circulating system of the human subject without any bad consequences ensuing. T. J. aged forty-eight, was admitted into University College Hospital July 2, 1840, for attempted suicide by cutting his throat. On admission there was found on the left side of the neck, about two inches below the ear, an irregular jagged wound, about three and a half inches in length, three cuts having been made; it was bleeding rather copiously. A surgeon to whom the patient had previously been taken had sewed it up. On the stitches being thrown loose, three arterial branches were secured, but the bleeding still continuing from the bottom of the wound, it was found that the left internal jugular was divided. On raising up the vessel in order to apply a ligature to its lower end, my friend Mr Morton, who was in attendance, distinctly heard the peculiar sound occasioned by the rush of air into a vein. He immediately applied his finger to the spot, so as to prevent the further ingress of air and tied the two ends of the vessel. The patient recovered without the slightest bad symptom.

being insufficient to cause death than to any effort on the part of the surgeon. The two principal modes of treatment that have been recommended consist in the suction of the air from the right auricle, and the employment of compression of the chest. Thus Amussat and Blandin advise us to introduce the pipe of a syringe, a female catheter, or a flexible tube into the wounded vein, if it be large enough to admit the instrument, and, if not, to open the right jugular and pass it down into the auricle, and then to employ suction so as to empty the heart of the mixture of blood and air. At the same time that this is being done we are, say they, to compress the chest as forcibly as possible so as to squeeze more of the air out of the heart. Magendie and Rochoux advise suction alone, and Gerdy recommends us to be content with compression of the chest. Warren (of Boston) directs us, according to the condition of the patient, to have recourse to bleeding in the temporal artery, to tracheotomy or to stimulants.

Before entering upon a consideration of these different plans of treatment, however, let us inquire what is the immediate cause of death in the cases in question, and consequently, what deleterious influences we have to counteract? It has already been shown in a former part of this paper, that death ensues in those cases in consequence of the air obstructing the capillaries of the lungs, and thus preventing a due supply of blood from reaching the left heart, and consequently being sent to the brain, whence the functions of this organ becoming suspended, the actions of respiration cease, from the want of a due maintaining power in the nervous centres. This, then, being the case, the indications that present themselves in the treatment are threefold.

1*st*, To keep up a due supply of blood to the brain.

2*d*, To maintain the powers of the heart until the obstruction in the pulmonic capillaries can be overcome or removed.

3*d*, To remove, if possible, the obstruction in the capillaries of the lungs.

We shall now see how far the means already mentioned, viz. suction, compression, &c. can fulfil these indications. And first, with regard to suction, it would no doubt be highly advantageous if we could by this or any other means remove the air that has gained access to the heart, and thus prevent the pulmonic capillaries from being still farther obstructed. But, putting out of consideration the difficulty of finding the wounded vein, the still greater difficulty of introducing a suitable tube a sufficient distance into it,—the danger of allowing the ingress of a fresh quantity of air whilst opening the sides of the incision in the vein so as to introduce the tube, and the risk there would be, if the patient recovered from the effects of the accident, of having phlebitis induced. Putting all these circumstances aside, which appear

to me to be most serious objections, it becomes a question, according to Amussat, who is one of the strongest advocates of this mode of practice, whether by suction with a syringe or the mouth even, any material quantity of air can be removed. He says, that even when the tube is introduced into the right auricle, much more blood than air is constantly withdrawn. These considerations, then, should, I think, make the surgeon hesitate before having recourse to such a hazardous mode of procedure.

The next plan, that of circular compression of the chest,—however valuable it may be in preventing the ingress of air, can, when that fluid has once been introduced into the veins, have no effect in removing it from the circulating system. We cannot, by any compression that we may employ, squeeze the air out of the heart. But compression may not only be productive of no positive good, but may even occasion much mischief, by embarrassing still farther the already weakened respiratory movements, and thus interfering with the due aeration of the small quantity of blood that may yet be traversing the lungs.

Bleeding from the temporal artery can by no possibility be productive of any but an injurious effect, by diminishing the already too small quantity of blood in the arterial system. Opening the right jugular vein may perhaps, to a certain extent, be serviceable by unloading the right cavities of the heart, as Dr Reid has shown it to be capable of doing, and it has been recommended by Dr Cormack on this account. Lastly, tracheotomy cannot be of any particular service, as the arrest of the respiratory function is secondary and not primary.

What, then, are the measures that a surgeon should adopt in order to prevent the occurrence of a fatal termination in those cases in which air has accidentally been introduced into the veins during an operation? Beyond a doubt, the first thing to be done is to prevent the farther ingress of air, by compressing the wounded vein with the finger, and, if practicable, securing it by ligature. At all events, compression with the finger should never be omitted, as it has been shown by Nysten, Amussat, Magendie, and others, that it is only when the air that is introduced exceeds a certain quantity that death ensues. All farther entry of air having thus been prevented, our next object should be to keep up a due supply of blood to the brain and nervous centres, and thus maintain the integrity of their actions. The most efficient means of accomplishing this would probably be the plan recommended by Mercier, who, as it has already been stated, believing that death ensues in these cases, as in prolonged syncope, from a deficient supply of blood to the brain, recommends us to employ compression of the aorta and axillary arteries, so as to divert the whole of the blood that may be circulating in the arterial system to the en-

cephalon. This appears to me to be a very valuable piece of advice, and to be the most effectual way of carrying out the first indication, that of keeping up a due supply of blood to the brain and nervous centres. The patient should, at the same time that the compression is being exercised on his axillary arteries and aorta, or, if it be preferred, as more convenient and easier than the last, on his femorals, be placed in a recumbent position as in ordinary fainting, so as to facilitate the afflux of blood to the head. The compression of the axillary and femoral arteries may readily be made by the fingers of two of those assistants that are present at every operation.*

For the fulfilment of the second indication, that of maintaining the action of the heart until the obstruction in the capillaries of the lungs can be overcome or removed, artificial respiration should be resorted to, as the most effectual means of keeping up the action of that organ. Thus Sir B. Brodie states, that he has seen, in a dog that was beheaded, and whose cervical vessels were tied, the contractions of the head maintained by artificial respiration for two hours and a-half, at which time there were 32 pulsations in a minute, and from my own observations, I can state that, by the same means, this organ may easily be kept in action in an animal that has been pithed, for an hour and a-half. For the purpose of keeping up artificial respiration, the Humane Society's bellows, if they be at hand, might be used, or, if they cannot readily be procured, a split-sheet might advantageously be employed. Before inflating the lungs, it will be necessary to remove everything that can compress the chest, or interfere in any way with the free exercise of the respiratory movements. Friction with the hand over the præcordial region, and the stimulus of ammonia to the nostrils may at the same time be resorted to.

The third indication—that of overcoming the obstruction in the pulmonic capillaries, would probably be best fulfilled by the means adopted for the accomplishment of the second, viz. artificial inflation of the lungs. That the action of respiration, if kept up sufficiently long, would enable the capillaries of the lungs to get rid of the air contained in them, appears to be the case, for I have several times observed that, if a certain quantity of air be sponta-

* I have repeated Mercier's experiment, and made several others on the curative means to be adopted in the cases under consideration, but without being able to come at any very positive result; and I believe that our treatment must be guided by our opinion as to the proximate cause of death rather than by any experimental inquiry, it being impossible to arrive at any definite conclusion by the latter mode of investigation. The same quantity of air, as nearly as one can judge, introduced spontaneously into the veins of dogs of nearly the same size and apparent strength, does not produce the same effects, proving very rapidly fatal in some cases, and not being followed by death in others; it is difficult to determine the causes of this difference, which probably depends on individual peculiarity or tenacity of life. At all events, it prevents our drawing any correct conclusions from the experiments.

neously introduced into the jugular vein of a dog, and artificial respiration be then established and maintained for half or three-quarters of an hour, but a very small quantity indeed, if any, will be found on killing the animal in the cavities of the heart, or in the branches of the pulmonary vessels. I am aware that this is not altogether conclusive of the fact, as the air might be dissolved in the blood, or might still exist in the capillaries of the lungs, although none might be found in the larger branches of the pulmonary artery; but still it seems to me that we can hardly account for the large quantity of air that will disappear, when artificial respiration is kept up in any other way than that some, if not all, of it passes out of the capillary vessels into the air-cells of the lungs.

It may be objected that this accident is so suddenly fatal that there would not be sufficient time allowed for the surgeon to put in practice the means just indicated; but it admits of question whether the rapidity of death in the human subject is so great as is generally stated. The anxiety and consternation produced in the bystanders by so fearful an accident as the introduction of air into a vein during an operation, makes the death of the patient, perhaps, appear more sudden than it really is; the cessation of the vital actions not being timed as in an experiment by the second-hand of a watch. In animals it frequently happens that a considerable time—half-an hour or more, in some of Amussat's experiments as much even as two hours and a-half, elapses before the introduction of air proves fatal. Now, although the tenacity of life may be much greater in the inferior animals than in the human species, yet in man even the length of time that has elapsed between the first entry of the air and the occurrence of death has been very considerable; thus Beauchesne's patient lived a quarter of an hour after the occurrence of the accident; Mirault's between three and four hours; and Clemot's several hours. Amongst the other recorded cases I have not been able to find any but vague statements as to the length of time the patients lived. Thus, then, it would appear that in some cases, at least, the surgeon would have ample time afforded him to put in practice the plan of treatment that has just been suggested.

If by these means we should succeed in warding off an immediately fatal termination to the accidental introduction of air into the veins, we must watch carefully for the supervention of pneumonia or bronchitis, which diseases Nysten has shown to be very apt to occur in those animals that recover the immediate effects of the accident. That the same danger exists in man is evident by the two cases that have occurred to MM. Roux* and Malgaigne† respectively. In Roux's case the patient lived seven days after

* Roux, Journal Hebdomadaire, Tome ii. pp. 161.
† Malgaigne, Gazette Medicale, 1836, pp. 166.

the accident, at the expiration of which period he died of pneumonia; whilst Malgaigne's patient died on the fourth day of bronchitis.

In recapitulation, then, the following are the principal points that it has been endeavoured to establish in this paper;—

1*st*, That the primary arrest of the circulation takes place in the capillaries of the lungs, or in the terminal branches of the pulmonary artery, in consequence of inability in the right ventricle to overcome the mechanical obstacle presented by air-bubbles in these vessels.

2*d*, That respiration and animal life cease in consequence of a deficient supply of arterial blood to the central organs of the nervous system.

3*d*, That as air enters the veins in quantity, in force, and in rapidity, proportioned to the depth of the inspirations, the best mode of preventing the occurrence of the accident, or, at all events, of lessening its probable fatality, would be, in all operations about the dangerous region,—the root of the neck and summit of the thorax,—to bandage the chest tightly with broad flannel rollers or laced napkins, so as to prevent deep gasping inspirations, and to keep the breathing as shallow as possible, consistently with the comfort of the patient.

4*th*, If air have already gained admission, prevent its further entry by compressing, or, if possible, ligaturing the wounded vein by which it had entered.

5*th*, Keep up a due supply of blood to the brain and central organs of the nervous system, by placing the patient in a recumbent position, and by compressing his axillary and femoral arteries.

6*th*, Maintain the action of the heart, by artificial respiration and friction on the precordial region, until the obstruction in the capillaries can be overcome or removed.

7*th*, Remove, if possible, the obstructions in the capillaries of the lungs by artificial respiration.

8*th*, If the patient survive the immediate effects of the accident, guard against the supervention of pneumonia or bronchitis.

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